Appendix D
Year 2005: Using Technology to Build Communities of Understanding

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Digital information technology is changing how people learn, teach, work, and play. By the year 2005, the capabilities and the affordability of digital technology could catalyze and facilitate the wholesale transformation of education and the communities that support it. SRI International's Center for Technology in Learning believes the effective use of this technology could alter the relationships between homes, schools, and workplaces and in so doing assist the creation of new kinds of communities (29,32). In this paper, we offer one vision of these new communities—communities that have learning and teaching at their core and use digital technologies to foster higher levels of community participation, enable deeper levels of cognitive and social engagement, and structure new kinds of relationships that support education. We analyze the social, pedagogical, and technological trends that support the realization of this vision, and we discuss the implications for teacher training, school accountability, and equity.

A community is a collection of individuals who are bonded together either by geography or by common purpose, shared values and expectations, and a web of meaningful relationships (33). In the communities that we envision in this paper—what we call "communities of understanding"—education is the common purpose, learning is highly valued, and a high level of academic achievement is expected of students and their schools. Mutual respect, honesty, and fairness are basic values, and there is a common dedication to see that each member of the community strives and succeeds. These values are enmeshed in the everyday activities and relationships of community life. There is a strong social network in these communities and a high degree of commitment to and involvement in the educational endeavor. This commit-

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ment is shared by students, teachers, parents, and other members of the community. Although this description may seem utopian, many of these qualities characterize successful learning environments in inner-city public schools of choice, Catholic schools, and Asian schools of today (5,17,35,37).

Clearly, these qualities can exist in a community, independent of advanced technology. And there can be communities based on geography rather than values or on values different from those described above. But in our vision for the year 2005, digital technologies are used to create a web of relationships, engagement, and participation that transforms the educational enterprise and makes it the center of community life. Today, schools, homes, and workplaces function separately—connected by geography and circumstances but infrequently by common purpose and collaborative action. But in our vision of communities of understanding, digital technologies are used to interweave schools, homes, workplaces, libraries, museums, and social services to reintegrate education into the fabric of the community. Learning is no longer encapsulated by time, place, and age, but has become a pervasive activity and attitude that continues throughout life and is supported by all segments of society. Teaching is no longer defined as the transfer of information, learning no longer as the retention of facts. Rather, teachers challenge students to achieve deeper levels of understanding and guide students in the collaborative construction and application of knowledge in the context of authentic situations and tasks. Education is no longer the exclusive responsibility of teachers but benefits from the participation and collaboration of parents, business people, scientists, seniors, and, of course, students of all ages.

How can technology support this transformation? First of all, the emerging information superhighway (18,38) will connect schools with each other and with homes, businesses, libraries, museums, and community resources. The connections between schools and homes will help students to extend their academic day, allow teachers to draw on significant experiences from students' everyday lives, and allow parents to become more involved in the education of their children and to have extended educational opportunities of their own. Connections between school and work will allow students to learn in the context of real-life problems, allow teachers to draw on the resources of technical and business experts, and allow employers to contribute to and benefit from the fruits of an effective educational system. Connections between schools, homes, and the rest of the community will enable students to relate what is happening in the world outside to what is happening in school, will allow teachers to coordinate formal education with informal learning, and will allow the community to reintegrate education into its daily life.

To make these connections pay off, this infrastructure will be filled with effective and engaging materials and tools that challenge students, afford new activities, and motivate learning. When users access the superhighway, they will find rich, multimedia resources in mathematics, sciences, and humanities and rich contexts of authentic situations and tasks. They will have access to tools that allow them to communicate and collaborate with others, consider ideas from multiple perspectives, express their ideas in multiple ways, build models, and explore simulations.

As important as digital information technology is to our vision of the future, we have deliberately avoided the temptation to become overly technocentric and speculative about cutting-edge developments. Because we have chosen to limit ourselves to technologies likely to be in wide use in 2005, our scenarios of the future are actually quite conservative on the technology side. The technological capabilities we describe are fairly straightforward extrapolations and amalgamations of the capabilities available today in advanced systems, which we believe will be affordable by schools and homes in the year 2005. No doubt, the cutting edge of technological capability will have advanced beyond those presented in the scenarios that follow.

Rather than emphasizing cutting-edge technology, we stress the collateral social change and educational reform that must occur for this transformation to be realized. To realize the full impact of digital technologies on our educational system, there must also be massive changes in the larger social structures, relationships, and interactions within which the education system is embedded. The forces constraining educational transformation are not technological but pedagogical and social. Where we have been daring with this paper is in developing a vision in which many of the educational, social, and equity issues facing our country have been addressed in systemic and positive ways. In our analyses, we describe the needed social and pedagogical changes that can support and be supported by the emerging technological developments. When advanced technology is integrated into a broad effort for school reform, then educators, students, parents, and communities will have a powerful combination that can bring necessary, positive change to this nation's educational system (21).

Our optimism is tempered by an acknowledgment of all the earlier technological revolutions that failed to change the classroom (10). On the other hand, our enthusiasm is buoyed by a growing number of policy discussions, community experiences, and educational experiments in social, pedagogical, and technological change at local, state, and national levels that seem to suggest that our visions are not outside the realm of possibility. Nonetheless, what we present is our *vision* of communities of understanding; it is not a prediction. We do not assert that this will happen, only that it can and should.

With that introduction, welcome to the year 2005.

A VISION OF THE YEAR 2005

Characters (in order of appearance):

- Steve Early, a 14-year-old African-American.
- Nelson, a 17-year-old living in South Africa; Steve's electronic pen pal.
- Carmela Zamora, 15-year-old of Philippine descent.
- Mr. and Mrs. Zamora, Carmela's parents.
- Valerie Spring, a senior teacher with a science degree.
- Sharon Gomez, a mathematics teacher.
- George Shepherd, an apprentice language arts teacher.
- Christopher Lindsay, a school-work coordinator.
- Lynda Lucero, a 13-year-old of Hispanic descent.
- Mrs. Lucero, a design engineer at the Global Car Company.
- Vincent Tracy, 14 years old and visually impaired.
- Other children, parents, and community members.

Settings: Some of the events take place in children's homes. Most of the events take place in the McAuliffe Learning Center, which serves as the physical locus for formal learning, community activities, and social services. McAuliffe is divided into a variety of spaces specifically designed for technology-supported learning. Facilities include learning-team pods, each with a workstation and project resources (microscopes, fabrication materials and tools, etc.); small-group meeting rooms, each with collaborative technologies, a flat-panel display, and personal interaction devices; multimedia production and editing suites; and a large multimedia auditorium and performance center. These resources are used by students and teachers during the day and are open to community members and groups at other times (see box D-1).

Social Perspective: Connecting Learning to the World

An important motivation for learning comes from membership in a community. The meaningfulness of a learning activity is increased by relating events that happen in the larger world to things that are happening in the student's world. The need to understand these events and do something about them creates a context and a motivation for learning. Connecting the informal experiences and learning of the outside world with the formal learning of the classroom makes the knowledge

BOX D-1: Scenario One: Connections to the World

As he does every morning, Steve Early eats breakfast in front of the teleputer. While he watches a news program m one window, his personal communication service relays a video message from his South African friend, Nelson, m another window. Nelson's vid-message is about a train derailment near his hometown that caused a huge hazardous-fuel spill, made people sick, and now endangers a wild-animal preserve. Nelson explains. "I am afraid the chemicals will poison our water and hurt the animals " Steve clicks on a button that Nelson embedded in the message and activates a "knowbot." This software agent presents the news story as it originated m Nelson's community and then goes off to search for additional information about the train accident on the GlobalNet. After Steve checks out the Net pointers, he constructs his own agent to search the local and national video news servers for other stories about the accident He Instructs his agent to find video clips that run less than three minutes, sort them chronologically, and store them on the school server so he can access them later, As he finishes his breakfast, Steve watches the video that the agent retrieved.

Meanwhile, another student, Carmela Zamora, is flipping through channels to the Hispanic MTV-News and hears about the South Africa train derailment. A budding naturalist, she is alarmed by the news and wants to do something to save the animals. When her dad comes in to remind her about getting off to school on time, he sees the news and they talk about it. Carmela shares her concern and asks, "What can we do to keep this from happening?" He tells her, "We all have to help. The telecourse I'm taking is to learn a new manufacturing process that will make the rail cars my company builds stronger and less likely to crack open if they are hit or fall off the tracks Maybe you'd like to come to the plant sometime and see how they're made "

Walking to school, Carmela meets Steve and asks whether his South African friend knows anything about the accident. "Yeah, he's worried. It happened close to his town, " he says In the playground, they meet up with three other members of their learning team, the Falcons. This morning, they must present an idea for a project to their teaching team. Carmela launches in, "I saw a report on the news this morning about an accident in South Africa. There was a fuel spill from a train near a wild-animal park I want to find out what can be done to save the animals. " "Me too, " Steve says, "My friend Nelson lives nearby, and I watched some video clips this morning that we could use. Let's ask the teachers if we can figure out how to stop hazardous spills from hurting the environment. "

The other three students agree. In the project planning room, teachers Valerie Spring, Sharon Gomez, and George Shepherd and the five students gather around the teleputer and open their project planning tool. Valerie Spring starts off, "OK, let's fill in the goals for the project. What do you kids have in mind?" The students chime in with their ideas.

"Your ideas about reducing hazardous spills sound interesting, " Ms. Spring responds, "but what would you like to do about it? What would you like to accomplish with your project?"

"1 would like to find a way to keep hazardous waste from hurting plants and animals, " Carmela replies.

"1 think we should get a law passed that makes tank cars safer, " says Steve.

"My dad's company is working on that, Steve. Maybe we could talk to him about that, " she says

"1 think that's a good idea, " says Ms. Gomez Always looking for a way to bring math into he conversation, she asks, "What other kinds of things might reduce the risks connected with transporting hazardous wastes?" Carmela puzzles for a moment and then offers, "In addition to making tank cars safer, what if we reduced the number of cars needed to transport fuel?" Steve adds, '(I wonder how many car loads of fuel are delivered in a year. " Excited by the prospect of a solution, Carmela volunteers, "What if we Increased the efficient use of fuel by 10 percent?" "We wouldn't need as much fuel, " Steve replies.

BOX D-1: Scenario One: Connections to the World (Cont'd.)

"Wouldn't it also reduce the number of cars on the tracks?" asks Ms. Gomez. "if we reduced the number of cars, wouldn't that also reduce the chance of accidents?"

"Yes, and it would also make the air cleaner, " Carmela shouts, "Let's think of ways to increase fuel efficiency"

Hanging on the wall is a large, color, flat-panel display for plotting the project. The use of pointing devices with the display makes it easy for students and teachers to rearrange the software symbols and objects that represent their developing ideas. Working with the display and the software planning tools, students and teachers develop the project's organization, timeline, and goals, as well as each student's learning objectives and tasks, As the discussion progresses, the teachers check the goals that students suggest with those listed in the curriculum. They also look at learning-history profiles that show each student's current knowledge in terms of the goals. The tool lets them see the skills, activities, and subject matter that past projects have emphasized The teachers suggest activities that will help the students gain the skills, knowledge, and experiences identified as absent from their learning profiles.

For example, in her planning tool, Ms. Gomez Indicates that the new project will help the students strengthen certain mathematical skills and concepts, including measurement of liquid volumes, graphing number relationships, and making mathematical connections to real-world problems. She also lists science facts, skills, and concepts appropriate to the project, including thinking critically and logically about the relationships between evidence and explanations, understanding ecosystems and organisms, and describing transformations of energy. Like most of her colleagues, Ms. Gomez has become adept at thinking in terms of broad, ambitious goal statements established by her school and district.

As a result of the discussions, the students decide to make an interactive multimedia report as their final product "You need to think about your audience for the report, " comments Mr. Shepherd, their language arts teacher, "and what they would want to know about your topic. "

"We need to think about why our report would be important to them, " adds Steve.

"If someone dumped fuel in your backyard, you would want to know how to stop it, " replies another team member. "Maybe we should show what happened to Nelson's neighborhood and then look for spills in our neighborhood, too, " adds a fourth member.

"But we need to find a way to stop it, " demands Carmela.

The students decide they will interview Steve's South African friend Nelson and ask his schoolmates to collaborate with them by gathering video images and other local information about the train accident that can be integrated with the information they create. They will also talk to community members in the McAuliffe neighborhood and see whether there have been any fuel spills in the area during the past year. Finally, they will come up with some suggestions for how to stop fuel spills. They will store their report on the community video server and make it available through the community-access cable channel and send it to Nelson and his South African classmates. The report will conclude by taking viewers to the Environment Chat Room on the GlobalNet, where they can talk to scientists, environmentalists, and others about the problem and potential solutions.

Each student has an assignment and downloads the project plan into a personal digital assistant with a beginning set of pointers to resources both inside and outside the neighborhood. "1 think we might really make a difference here, " Steve says. "1 can't wait to tell Nelson. "

acquired more useful and the world outside more comprehensible.

Technology helps motivate learning by bringing the world into the learning environment and increasing the authenticity of learning activities. Today's technologies—television, telephones, computers, electronic mail, and videodisks----offer ways of infusing real-world issues into conventional, discipline-based curricula. However, the usefulness of these technologies is limited by a paucity of interactivity—there is not much the student can do with this information. As technology evolves during the next decade, a host of personal communication and information services will become increasingly understandable, affordable, and accessible to consumer and education markets.

An interactive connection with the world can dramatically increase learning resources. Teachers and students can get access to expertise and information not otherwise available. More importantly, students can *do something* within this technological environment. They can interact with and influence other people. They can explore far-off continents, and they can add to the contents of far-off libraries. They can share a museum visit with their schoolmates or take a field trip without getting on a bus. Scientists can come into the classroom, and students can go off into space. They can identify people with similar concerns and find others who can help them solve their problems. This interactive web of people and resources can become a foundation for building the community of understanding.

Pedagogical Perspective: Project-Based Learning

In recent years, consensus has evolved around a set of National Education Goals to improve student learning. By the turn of the millennium, the individual states and local school systems are likely to implement these goals into an extended set of standards that students must achieve (for example, see references 6 and 7). These will serve as a focus for the design of learning environments and activities. Prominent among the National Goals is the objective of increasing student ability to solve problems and demonstrate competency over challenging subject matter, particularly in mathematics and science. In our vision, the "learning project" is the mechanism used to accomplish these goals.

Project-based learning involves students in the identification of some problem or goal of personal or group interest and the generation of activities and products that will accomplish the goal or solve the problem (4). Within this framework, students pursue solutions to nontrivial problems, ask and refine questions, debate ideas, design plans and artifacts, collect and analyze data, draw conclusions, and communicate findings to others. Because they bring problems in from their own personal lives, students are more motivated to pursue a deep understanding of a cluster of topics across related domains. This approach contrasts with the current practice of superficial coverage of many topics in a single domain.

The project is also a way of valuing and integrating knowledge from multiple perspectives and multiple disciplines. Naturally occurring problems are not compartmentalized into mathematics, science, and language arts. Furthermore, problem solutions benefit from the multiple expertise, perspectives, and modes of expression that come from multiple members of teams—both teams of students and teams of teachers. No one person is likely to have the solution to complex, real-world problems, and differences among students in expertise and experience are valued.

Project-based learning, particularly projects that emerge from student-identified interests, makes planning and accountability more complex. The challenge for teachers is to begin with these student-generated interests and guide the development of a particular project to make sure that students are challenged and that they accomplish important educational objectives. They must build on individual strengths and accommodate the individual needs of students within the group. In addition, they must work with students to generate productive activities and provide them with access to useful resources.

Technology can help both teachers and students manage the complexities of project-based learning. In the scenario above, teachers and students use project software to help them keep track of student progress with respect to curriculum goals. Teachers use the software to support students in structuring their projects by providing students with access to resources and activities they can use to accomplish their goals. And students benefit when they externalize their ideas by representing them explicitly as concrete objects with which they can interact more easily. Finally, both teachers and students can use the environment to share experiences and resources with others.

Pedagogical Perspective: Scaffolding

"Scaffolds" are external aids that provide cognitive and social support for people new to a task or knowledge domain, much as scaffolds on a construction site support workers and materials while a building is erected. These external aids consist of questions, prompts, or procedures provided to students that more knowledgeable people have internalized and provide for themselves. By performing part of the task, scaffolding allows students to manage tasks that are more challenging than the ones that they could do on their own (41). When these aids are a normal part of the classroom discourse, students can model these skills for each other and get assistance from the teacher and others in the group (25). As students refine and internalize these new skills, the supports are gradually withdrawn and students perform more of the task on their own.

Problem solving and critical thinking are particularly challenging curricular goals for young students. They must learn to analyze problems and specify goals, identify information and plan activities that will help them solve the problem, identify the products of their work and specify criteria that will be used to evaluate them, and work as a team to accomplish their goals. The use of scaffolding helps students work through these cognitive and social processes. By using these processes repeatedly across projects, students will come to generalize them, take them out to the real world, and apply them to problems they encounter there.

In our scenario, students use a combination of technological and social supports to scaffold their problem solving. They use a computer-based project tool along with the guidance of teachers and each other to design and manage their project. The tool and the teacher team scaffold students' work by stepping them through the planning process, asking them to define their goals, prompting them to select activities to accomplish these, guiding them to resources, and structuring their assessments. Students begin to use these prompts socially with each other, and ultimately the skills become internalized and they can use them on their own. While students work on their project, the tool keeps their goals and plans visible so that they do not lose track of them while in the thick of their activities.

Technological Perspectives

In this scenario, a number of technological tools and software utilities support student learning and connect it to the experiences, resources, and people in the outside world.

Computer-Based Planning Environment

Although pedagogically appealing, project-based learning and scaffolding present new challenges to teachers and learners. Teachers need help to ensure that open-ended, bottom-up, project-based approaches provide a comprehensive, balanced education, and learners need help in planning and executing their projects. Technology can provide this help.

Embedded coaching systems and intelligent critics that assist users while they are actively carrying out their tasks are beginning to appear in commercial products (for example, Apple Guide in Macintosh System 7.5) and will become much more common in learning software environments in the next 10 years. These approaches are particularly effective for open-ended exploratory environments (14) that emphasize the discovery process as well as project design and development. These software coaches and critics will provide timely curricular support for teachers, and, along with the teachers, scaffolding for students.

In this scenario, teachers and students use a project planning tool that helps provide students with guidance and feedback on the design, development, and execution of their projects. By constructing a "learning-history profile," or model of each student's current knowledge state, the project planner functions as an assessment tool that enables teachers, students, and parents to see areas that past projects have emphasized, as well as the objectives a student might address in the current project. In the process of constructing their project plan, the students and teachers work with the tool to decompose each activity into its constituent curriculum objectives. The tool makes suggestions for improvements to the project by referring to similar cases and draws from a database of activities known to have been successful in the past. A record for each activity in the database contains a description of the activity, a set of links to useful content, and a list of technologies these students will need to use to meet their learning objectives. Over time, the use of such tools, in the context of project-based learning, supports deep engagement in problems and content without sacrificing the comprehensiveness of the curriculum.

Integrated Personal Communication Services

Current approaches for exchanging electronic messages assume that users send, receive, and store messages within a single information utility (such as the on-line services CompuServe or America Online). These electronic communication services are separate from services for communicating by voice and from other information services, and these differences create difficulties and barriers for users. Several trends suggest significant changes by 2005 that will integrate these services, and make them easier to use.

For the past few years, telephone services have expanded to include voice mail (voice messaging) and personal telephone numbers (unique addresses). The telephone companies are increasing the capability of their infrastructure to transmit text and high-quality audio and digital video, and, as a consequence of recent FCC rulings, they are beginning to offer these services on a limited and experimental basis. Similarly, trends in the cable television industry suggest that, besides video-on-demand, cable providers plan to offer message services and access to the kinds of databases currently carried by information utilities. Despite the falling through of the proposed TCI/Bell Atlantic deal and the failure to pass federal telecommunications reform legislation, the complementary capabilities of communication companies continue to make them attractive partners (1,36), as witnessed by the recent Intel/AT&T deal to develop services for corporate video phones (39). Extrapolating these trends, it will not be long before an array of familiar consumer products can be used to send and receive digital messages in a variety of forms with a variety of devices at prices similar to those currently charged by cable providers, telephone companies, and other information utilities.

In this scenario, when Steve checks the personal communication service on his television for vid-messages, he does not leave the television experience and go to a desktop computer to enter a communications mode in a different medium (that is, text). Because of windowing and multitasking features offered by his “teleputer, “ he mixes the informational perspectives Nelson sent him from South Africa with those available from his local news service. These capabilities allow him to more seamlessly intermingle South African perspectives with local ones and to connect these perspectives with other information available in the system. Nor does Steve have to interrupt the train of thought he developed during his news viewing experience to log on to an information utility. The integration of services frees the cognitive capacity normally used to operate different systems and allows a deeper engagement with the ideas contained in the messages.

Smart Mail, Intelligent Agents, and Programming by Example

As a result of the integration of information and communication services, the amount of information and the number of people available on the network increase dramatically. Tools will be needed to make this mass of information useful and usable. Smart mail, intelligent agents, and programming by example will increase the power of communication, decrease the difficulty of finding and using information, and make the system easy to operate.

General Magic has recently organized a consortium of companies—including Sony, Motorola, Apple Computer, AT&T, Philips, and Matsushita—to develop personal communicators and advanced communication software and services to be offered at prices geared to the average consumer. The heart of these services is a communication-oriented programming language called Telescript. In Telescript, each message is an agent, or a "knowbot." The agent is a small program that can perform functions besides just expressing a text message, such as searching, collecting, organizing, and distributing information to certain people at certain times. In the future, scripting languages like Telescript will enable users to add computational capabilities to their messages (27).

For this technology to be broadly successful, the ability to construct a smart message cannot require a user to learn a difficult programming language or write lines of code. New approaches are simplifying this task by allowing users to "write" a program by example (11). In programming by example, a software agent monitors a user as he or she performs a task, such as constructing and sending a message. The agent forms a model of what the user is doing, and once it is "confident" that it understands the process, it will offer to carry out the actions in the future. Thus, by simply performing a task, the user creates a program that the system can implement under similar future circumstances. By 2005, such approaches will be so evolved that users will be able to construct agent scripts so naturally that they will be completely oblivious to the fact that they are "writing" a program.

The "smart" message Nelson sent Steve includes a set of computer scripts, which, when triggered, link Steve to more information. Nelson wanted Steve to see the train derailment and chemical spill from a South African and other perspectives, so in his message he included a hypermedia link that Steve can follow to see the South African news clip and an agent that Steve can activate to search for information about the train accident on the GlobalNet. Steve also constructs his own agent to search for and organize additional information of a certain kind. Construction of this agent is easy because these are the kinds of things Steve usually does with information, and the agent knows that (see box D-2).

Social Perspective: Connecting Learning to Work

Society is recognizing that students must be better prepared for productive jobs within the competitive world market and that those skills and knowledge could be better obtained if academic work more closely resembled authentic work. Reports such as *America's Choice: High Skills or Low Wages!* (24) rang the alarm that the United States is not providing an education that prepares young people for productive careers in the technology-dependent and highly competitive 21st-century work environment.

School-to-work transition programs should help students acquire the conceptual underpinnings of the skills they learn without becoming trapped in training on specific procedures or equipment, much of which will be outdated by the time the students enter the adult work world. Ideally, students should be exposed to both the practical contexts and the meaningful tasks of adult work as well as the conceptual knowledge and generalizable skills normally associated with formal learning (31). The teacher guides the transfer of knowledge between these two areas and helps students reflect on their experiences.

With this approach, students should be challenged by tasks that:

- Have analogs in adult work, but also reflect students' interests.
- Are complex and open-ended, requiring students to work through the definition of the problem and regulate their own performance.
- Relate to practical situations so that experiences from work and daily living provide important information, strategies, or insights.
- Can be accomplished in multiple ways, typically with more than one good answer or outcome.
- Are performed by student teams, with different students taking on different specialized roles.

BOX D-2: Scenario Two: Connections to Work

Later that day, Carmela and Steve join one of their other learning teams the Cheetahs which is designing a car to compete in the National Cyberspace Derby against cars created by students from other communities around the country, The team is preparing for the regional competition; the winners compete in the national finals. Students are coached by school-work coordinator Chris Lindsay and math teacher Sharon Gomez, Chris Lindsay starts the meeting: "There are two designs you folks have been working on; we need to decide which one we will use to compete in the regional, "

"Lynda and I want to race our fastest car, " explains Vincent Because he is visually impaired and cannot see the car being designed, Vincent relies on auditory and tactile feedback provided by the computer system, As he traces his hand over a flat-panel display, the system provides auditory information about the coordinates he is interacting with, He has learned to use this information to build an image of the car in his mind At the same time, graphic and text information is fed to a Braille printer so he has documented information that can be used in the future and shared with other blind students, "I like this design, " he says, "Now that we have modified the spoiler and tuned the manifold, this should be the fastest, "

"Remember, the race rules state the best overall car wins, " replies Ms. Gomez, "What other factors do you think you need to consider, given that rule? What might the judges include in determining the best OVERALL?"

Carmela responds, "Well I've been thinking about a new hazardous-waste project that Steve and I are working on, and I think building the most fuel-efficient car will be safer for the environment "

'(Yes, and thinking about it from a business view, what about the cost of production? You do need to make a profit, right?" offers another team member

With these ideas in mind, the student team consults with an engineer who works at the local office of Global Car Company, an automobile manufacturer and one of the race sponsors, The engineer is also the mother of team member Lynda Lucero. For weeks, Ms. Lucero in person and remotely responds to students' questions as they encounter problems with their designs, The students use a high-end workstation and computer-aided-design (CAD) program supplied by Global Car, The students' CAD tool has all the basic features of professional design tools but runs on less powerful and less expensive computers than the one in Ms. Lucero's office. However, the two machines are connected so that the same image appears on both screens and can be altered by both the students and the engineer,

- Are performed with the same information and the same kinds of technology tools (though not necessarily identical tools) that are used by professionals.

Networked communications and collaborative software can be used to create new relationships between work and school. As reflected in this scenario, teachers and experts from various professions can jointly design realistic activities based on authentic tasks that motivate the learning of generalizable skills and concepts. Teachers provide an overall structure, assess student work and create ways for student self-assessment, and point out linkages between project activities and the concepts under study. Mentors work with students on specific tasks, providing guidance and assistance when students reach an impasse, modeling the way practitioners in the field solve problems and providing guidance that is not associated with the grading process. All of this is supported by the electronic infrastructure and a set of software tools.

Pedagogical Perspective: Modeling

There are two meanings for the word *model* (15)—an "of' meaning and a "for" meaning—and

BOX D-2: Scenario Two: Connections to Work (Cont'd.)

Ms. Lucero's image appears in a small window in the corner of the screen next to the large window that displays a wire-frame model of their favorite design. Back in her office, she uses her stylus to lower the roof line on the model, and the students see the results on their monitor "If we make the roof line lower, it looks better and it will reduce friction—or what we call the drag coefficient—which results in increased fuel efficiency, However, manufacturing a sleek racing car can be expensive, and you have a limited budget for your design, This is what your teachers mean when they talk to you about 'constraints' in design. You are going to need to think carefully about whether to spend that money on a better engine, a more comfortable interior, or reducing the drag. " The team discusses these and other complex issues with Ms. Lucero.

The cars the students create are not static drawings but functioning models that they can test on a simulated cyberspace race track. So after they make changes to their cars, Ms. Gomez has the students conduct simulations to test each change scientifically by running the car and studying the effects of their changes on speed/fuel consumption comparison graphs. To increase their understanding of the issues, working with Ms. Lucero, she introduces them to velocity and acceleration graphs. The students begin to see that there is a lot of math and physics as well as artistic talent revolved in making a car that is attractive, fast, and fuel efficient,

At the end of the mentoring session, each student uses a personal digital assistant (PDA) to record new information and knowledge and a reflection on the day's activities in a "learning log, " Meanwhile, as they work with each Iearning team, the teachers use their PDAs to keep track of new skills the students have demonstrated and their impressions of how well the exercise fosters collaborative skills.

"OK, team, " Ms. Gomez announces, "everyone please put a note in your PDAs so you'll remember to have the people in your family conduct a simulated test drive of the prototypes by next Monday You'll need their comments on how each car handles. Ask them to compare each design to the cars they drive Remember, customer satisfaction counts, too. "

"The race is just two weeks away, " Mr. Lindsay reminds them. "You must decide on the final design by the end of the week so there's plenty of time to prepare your multimedia reports and rehearse your presentations. You will have to explain why you designed the car the way you did, Remember, we've invited families and neighbors to watch the race, so you need to be sharp. "

both are relevant to new pedagogical approaches. In the first sense, models are constructed, symbolic artifacts that simulate the "real thing" in some important ways. These artifacts may be scale models, flow charts, or computer simulations that display or operationalize the structural or functional relationships of a physical system, such as a mechanical device, or of a conceptual system, such as Newton's laws of motion. By building, manipulating, and explaining the design of such models, as illustrated in the scenario, students come to understand these structural and functional relationships (42). When modeling a phenomenon, students must represent their understanding of the world in an explicit way, as the students did with their design of fast, fuel-efficient cars in the scenario above. By representing these phenomena explicitly, students may uncover weaknesses in their understanding that they can work to correct. If students operationalize their understanding in computational models, they can compare the behavior of these models with the behavior of real-world phenomena, using these to judge the validity and reliability of what they know.

In the second sense, a model is a symbolic representation of something that is intended to become real. In this sense, behaviors, practices, and attitudes are modeled with the intent that students will come to be like these models. In cognitive apprenticeships, an expert carries out a task so that students can observe and understand the processes that are required to accomplish the task (9). This modeling requires the externalization of cognitive processes and activities that are usually performed internally. In the scenario above, Ms. Lucero was modeling how designers think, solve problems, and use their tools. In demonstrating the process by using the shared CAD tools, she not only modeled the use of the tool but the decision processes and procedural knowledge that are used to design cars.

Technology can be used to help make these internal processes external and observable while students are working on their authentic task. As well, the system can keep track of students' processes and make these traces available to both student and mentor. These traces can become the focus of cognitive mentoring in which both students and mentor examine the thinking processes behind specific decisions. Thus, the students' thinking processes themselves, as represented in these traces, can become a direct object of mentoring.

Pedagogical Perspective: Collaborative Problem Solving

Traditional school learning emphasizes individual achievement and solving problems without the aid of other people or resources (28). Although this approach works when learning facts and solutions to simple, contrived problems, it is insufficient for the application of knowledge to solve the complex problems of the adult work world. In the real world, complex problems are frequently solved by teams of people who bring to bear a variety of perspectives and expertise. Preparation for this environment involves learning to collaborate and to use a variety of tools and resources.

Collaborative learning focuses on problems rather than topics and engages students in activities where they produce and promote theories, interrelate ideas, and explain how things work or how they are caused. This shifts the pattern of discourse from teacher-initiated questions, followed by student responses and teacher evaluation, to a pattern of teacher- and technology-supported discourse in which students initiate inquiries, provide responses, and evaluate each other's contributions. That is, the focus of education shifts from teaching to learning.

Technology can be used to structure and facilitate this collaboration. Currently, there are several technology-based learning environments that illustrate this capability. Scardamalia and Bereiter's (30) computer-supported intentional learning environment (CSILE) is structured so that the students use a computer to collaboratively build a text and graphical database of information on topics of mutual interest. In creating this database, students engage in electronic interactions in which they pose problems, ask questions, and share their understanding. Pea (26) provides a graphical simulation environment with which groups of students construct ray diagrams that replicate actual or videotaped experiments illustrating principles of light and vision. White (42) designed a simulation environment with which students formulated and tested hypotheses about force and motion. Environments such as these, and the CAD environment in the scenario above, when used along with appropriate educational activities, transform the roles of students from recipients of transmitted facts to active participants in knowledge-building communities.

Technological Perspective

In this scenario, the school's computers provide processing power sufficient to render and manipulate CAD graphics and run simulations. The software enables students to create powerful project documents quickly and easily. In addition, the collaborative software, coupled with a broadband network infrastructure, makes school-work mentoring a reality. These capabilities enable new relationships, new levels of participation, and new activities that support connections between school and work.

High-Performance Workstations

According to "Moore's law, " the density of computer chips quadruples every three years. This trend is expected to continue until the year 2000, when extrapolation suggests that a single memory chip will store 256 million bits. The 256-million-bit figure may be slightly optimistic, however, since Meindl (22) predicts that growth will slow down sometime in the near future. Using Meindl's projections, the density of chips will grow at 20 to 35 percent per year through the year 2111. If that trend—and a similar trend of increases in processing speed—holds, computers developed and priced for consumer and education markets will be able to process data at speeds approaching 400 MHz by 2005.

While power and speed quadruple every three years, historically computer hardware prices drop by half. Following similar trends, prices of RAM and VRAM will continue to fall and enable learning environments to upgrade workstations so that they can render and manipulate detailed graphics images at speeds greater than those afforded by today's dedicated graphics workstations. Additionally, the cost per megabyte of storage will drop to enable storage systems for low-end workstations to reach into the gigabytes.

Consequently, in this scenario, students use what would be considered, by today's standards, a high-end graphics workstation to develop their cybercars. These students and teachers take advantage of this processing power by working on authentic and appealing car design problems to learn physics and math.

Compound Documents

Supported by trends in object-oriented programming, software developers are moving away from current applications-centered models of software development toward document-centered approaches. Applications-centered models focus on separate task clusters, like writing or budgeting, and design software with functionality that corresponds to these clusters, such as word processors and spreadsheets. This model assumes that users enter a task mode (such as writing) and will need only the functionality pertinent to that mode, as narrowly defined. Therefore, a user who wants to add pictures and sounds to a document must move back and forth between several other software packages (such as a graphics or sound package) and deal with the operation of these other programs.

Document-centered approaches assume that users will want access to different tools all the time. Thus, document-centered approaches encapsulate functionality in software components that users can access within any document. For example, instead of working with a word processor, drawing application, or spreadsheet, users can work within generic documents and import into those documents the specialized capabilities needed to perform specific tasks. This capability will make systems easier to operate and tasks easier to perform. As with integrated communications technologies, a document-centered approach frees the cognitive capacity normally used to operate different systems and allows users a deeper engagement with their ideas.

In this scenario, document-centered approaches enable students to easily import dynamic modeling capabilities into their designs, so that their cars can actually race in cyberspace. They can also export components of their design document into their multimedia report document, so that they can demonstrate design features as they present the rationale for their design.

Simulation and Modeling

The opportunity to model a phenomenon offers students a significant new way to represent and operate on their understanding of the world—in this case, a world of cars, what makes them work, and how they are designed. Document-centered approaches enable students to import "smart objects" from a car design object suite into their project document. The objects themselves "know" how they can interconnect. And because these objects are fashioned in view of an overall model of how cars operate, when interconnected they can contribute to critiques of students' evolving car designs. These objects also “know” about properties of the world in which cars operate.

Consequently, when students carry out simulations, they receive feedback about performance and efficiency. For example, in this environment, students can even carry out wind tunnel simulations, which, with the help of visualization, enable them to assess the aerodynamic efficiency of their designs. Thus, the technologies that support modeling constitute a learning environment that involves students in a systematic process of recursive design—a process that requires them to construct a grounded understanding of physics and math while simultaneously developing a mental model of systematic inquiry.

Collaborative Computing

Currently, researchers are focusing a great deal of attention on workgroup computing, also known as groupware or computer-supported collaborative work environments. These are hardware and software environments that connect people, perhaps at different sites, to work on shared tasks. These environments allow users to exchange and work on shared documents, in synchronous or asynchronous mode. The connections may provide for the exchange of formatted files, voice messages, graphics, or video. The environment scaffolds collaborative problem solving and design. Computer-supported cooperative learning environments are just beginning to spin out of these technological developments (26, 30, 31).

Because they have access to collaboration capabilities, when students in the scenario above reach a stumbling block in their approach, they can connect to a car design expert who shares their document space. Ms. Lucero not only sees the design that the students are creating, she can manipulate this design on her workstation. The students can see and hear Ms. Lucero and see what she is doing with the design, and they can work together on its development. The collaboration environment also records a history of the group’s design, so that Ms. Lucero can see earlier versions of the design and review the design process. The expert collaborates with students to solve special problems that teachers do not have the expertise to tackle, and she collaborates with teachers to create authentic tasks and experiences for the students. In this way, the technologies enable new kinds of relationships and new levels of participation that can support learning.

Assistive Technologies

Advances in computer and other technologies have long offered the potential of enhancing the education of children with disabilities, and in the past decade, many applications of software, computer peripherals, and other technologies have been developed or adapted to increase the participation of these youngsters in learning experiences. Because of the increasing awareness and acceptance of disabilities in our society, and the rapidly accelerating pace of technology development, we foresee an increasing range of assistive technologies by the year 2005.

The full range of children with disabilities who can benefit from technologies is too broad for us to address in this paper. For this reason, in our scenario, we have selected just one area on which to focus attention—visual impairment. Currently, there are a number of assistive technologies designed to help persons with visual impairments. They include fully speaking, hand-held dictionaries, screen readers with audio feedback that allow the user to get an audio “dump” of a computer screen, Kurzweil readers, Braille printers, and so on.

In our scenario, assistive devices designed for the visually impaired and specialized interfaces for technologies used by his fellow students enable Vincent to share his learning experience and reduce the isolation his disability imposes. For example, students with no visual impairment might be using a graphical user interface (GUI) to interact with the software; Vincent would use speech recognition technology and an interface that uses the same graphic metaphors but presents them in words (40). In addition to recognizing his speech input, the technology provides Vincent with the same information that others can read on a screen as text or graphics. This can be done by translating this information to voice, so that Vincent can hear what is on the screen instead of seeing it. In our scenario, we have also projected that Vincent could use a touchscreen to enable him to visualize graphics or schematics, the information being provided to him by voice according to the coordinates that he touches on the screen. These powerful assistive technologies not only increase the participation of disabled students but provide students with environments of equivalent experiences that enable new relationships between disabled students and their nondisabled friends (see box D-3).

Social Perspective: Connecting Learning to the Home

A key factor in building "communities of understanding" will be the extension of learning environments to include home and parents. Although most parents want to be involved in their children's education (13), a number of factors make this difficult. The rise of single-parent and dual-career families has reduced the amount and flexibility of time that parents have to assist their children and communicate with teachers. Some parents are inhibited by cultural differences, feelings of mistrust, or their own lack of education. Unfamiliar curricula and recent developments in knowledge make it difficult for some parents to draw on their own education to help their children. As a result, parents of all educational backgrounds believe they are ill-equipped to help. Several national surveys of parents of all income levels have found that they want schools to tell them how to help their children at home, and they want more information about their children's performance in school (16).

Teachers face similar constraints on their time. Many lack training for dealing with parents or have difficulty relating to culturally different families. But studies show that school programs that support parental involvement affect participation more than other factors, including the parent's race, education, family size, or marital status, and even student grade level (13,16,23). Parents whose children's teachers involve them in the learning process report feeling more compelled to help, report that they understand what their child is being taught, and rate the teacher higher in overall teaching ability and interpersonal skills.

When parents are involved with children's learning, teachers maintain higher expectations for students and report stronger, more positive feelings about teaching and their school. They also are less likely to make stereotypical judgments about poor, less-educated, or unmarried parents than other teachers do.

Most importantly, the children of involved parents—especially students from low-income families and ethnic minorities—earn higher grades and test scores (16). Schools also perform better when parents are involved at school. It is estimated that when as few as a third of the parents become actively involved, a school as a whole begins to turn around (16). The performance of all children in the school tends to improve, not just that of the children of those who are more involved. The highest level of student achievement happens when families, schools, and community organizations work together.

The increased presence and connectivity of technology in the home can increase the level of parental involvement by making it easier, more convenient, more interesting, and more productive. Connections with the school can not only accommodate parents' time constraints, but they situate parents' interactions with teachers in the comfortable, familiar context of home experiences and tasks.

In this scenario and the first one, a number of school programs and technological capabilities support parental involvement and communication between the school and the home. Connections between school and home allowed Mr. Zamora to participate in Carmela's experience even though he could not attend. He is also able to help her and her classmates within the constraints of time and place. Finally, he is able to use technology to extend his own learning. Other activities and services facilitated by these connections could be:

BOX D-3: Scenario Three: Connections to Home

Four weeks later, the families of the students and other community members gather to cheer on the student teams as they pit their cars against others in the finals of the National Cyberspace Derby. Steve and his parents walk into the performance center where the other students and neighbors are gathered. Excitement is thick in the air.

"Thank you, everyone, for joining us this afternoon, " Mr. Lindsay, the school-work coordinator, says. "We appreciate Global Car Company's sponsorship of this race and providing the students with our engineering mentor, Ms. Lucero. In the finals, the winner of the race wilI be the car that is the fastest while getting at least 40 miles per gallon of fuel. All cars have raced in series of regional qualifying runs, and now the best 12 will compete in today's final race. These cars have already rated high on tests of user satisfaction and have come within production budgets. "

On the large projection screen, the audience sees the race from four perspectives. In one window, there is an overhead view of the entire track and the position of each car. Another window displays the track from the driver's seat as students maneuver among their competitors. A third view focuses on the car's instrument panel of gauges showing speed and fuel consumption. Because each car is a computational model, the students can tap into any car on the track, read its gauges, and display them in a fourth window

Lynda, Vincent, Steve, and Carmela huddle around their teleputer as the voice of the announcer comes through the speaker. "Good luck, everybody. Ready, set, GO!"

As the audience cheers, the McAuliffe Cheetahs accelerate their car around the track, moving to the front of the pack

"You're off to a good start, " Ms. Lucero cheers

As the cars lap the cyberspace track, two cars from other communities pull ahead. "Look how much fuel they've used, " yells one parent, pointing to the projection screen. The audience watches the indicator drop quickly as the car in the lead bursts ahead. "See our fuel gauge; we still have plenty left, " Steve shouts.

The community audience groans as the cars reach the finish line. Two cars cross the line ahead of theirs. Then the voice of the announcer says: "While the first two cars that crossed the finish Iine were the fastest, the winner is the car that is both fast and fuel efficient, so our winner is the car that crossed the line third: the McAuliffe Cheetahs!"

Later that night, those from the community who couldn't attend the race live can access a replay of the race on the community's dedicated learning channel. Carmela returns home with her mother to find her father finishing up his latest telecourse lesson. "Congratulations!" he beams. "1 watched the results in the background while I was working on my lesson. Great job!"

Carmela smiles back, "1 knew we could win if we made it more fuel efficient. We checked the fuel efficiency every time we changed the car design. Keeping track of fuel efficiency is really important. We are using it a lot. Ms. Gomez asked us to enter the fuel efficiency of our family cars in the class database for our project on hazardous spills. Can you help me transfer the data from our car's computer?"

Mr. Zamora reaches for the family PDA and calls up the database for their car. The database is automatically updated by wireless communication every time the car pulls into the garage, so the family can keep track of its efficiency and catch problems before they become big ones. "Let's link these data to your classroom database, like this, and it will automatically be updated, too. Let's sit down tomorrow night and go over the data together. We can look at why some cars are more fuel efficient than others "

"Dad, will you mentor this project?" Carmela asks. "The kids want to see how the rail cars are built so they don't spill hazardous waste "

"Sure, let's send electronic mail to your teachers asking how I can help, " he says. "But first, let's replay that winning race!"

- Videotext service and dedicated school video channels that provide continual updates of school activities.
- Electronic mail or voice-mail messages that allow parents and teachers to discuss student progress asynchronously, at times convenient to each.
- Video programs that explain student assignments and provide tips for how parents can participate and help.
- Computer-based assignments, educational projects, and multi-player games that parents can do with their children.
- Extended video-based programs or mini-courses that supplement parents' knowledge of a range of topics from parenting skills to school subjects.
- Switched, interactive video so parents and other community members can tutor children from their homes.
- Community-access video servers that allow parents to share personal photos and audio and video recordings of historical note or personal meaning.

Pedagogical Perspective: Authentic Assessment

Paralleling several other developments described above, there is a national move to change student assessment so that it reflects knowledge as it is used in the world rather than knowledge in the classroom. Authentic assessment moves from the recall of facts and the computation of "answers" to the application of knowledge in situations similar to those in which knowledge will be used in the real world. Correspondingly, judgments are made on authentic processes and products, and the "correctness" of these assessments moves from being the sole responsibility of the teacher to being the shared responsibility of those who participate in and are affected by the application of knowledge.

- Authentic assessment can be supported by technology in many ways, including:
- Designing multimedia assessment tasks that present richly textured scenarios.
- Allowing learners of disparate knowledge, learning styles, challenges/impairments, and language to be equally engaged in the assessment process.
- Archiving the learning process, draft materials, and finished products.
- Recording time spent on tasks and tracking scaffolding.
- Supporting "remote" evaluation of student work.
- Publishing student work and making it available to parents and others in the community.

Pedagogical Perspective: Multiple Representations and Visualization

External representations are the primary means by which people come to understand a phenomenon or concept and express this understanding to others (20). We use words, pictures, sounds, diagrams, numerals, and other symbols to construct these representations and convey meaning to others. Each type of symbol, or symbol system, expresses the meaning of a phenomenon or concept in a different way. A picture of a car racing down a track says something different from the equation $f=ma$, yet both say something about motion, force, acceleration, etc. Making connections across symbol systems or representations is important; in fact, the ability to make these connections is frequently what we mean when we say someone "understands" something. For example, someone understands $f=ma$ when he or she can read a paragraph about speeding cars and use the equation to determine which car will go fastest or need the least force to accelerate.

Technology can be used to support understanding by providing students with one or more symbolic representations of a phenomenon or concept. Students can act on these in some way and observe the results. These multiple coordinated representations can make difficult concepts more accessible to students, and students can build a deeper understanding of the concept by combining the different information provided by each representation (19,20). For example, a student could enter an equation and the technology could provide a graph of the equation. As a consequence, the student has a deeper understanding about both equations and graphs. Or the technology can build on a student's understanding as represented one way to understand the phenomenon as expressed in a different way.

"Stepping on the gas" is a common, everyday experience for students. In the scenario provided, the students can manipulate the graphic object of a racing car so as to "step on the gas" (that is, increase the force), thus increasing its velocity and acceleration. Not only do they see the car speed up (a consequence with which they are very familiar), they also see a numerical representation of its speed and see this numeral change over time. They also see a graph of the relationship between force and acceleration. Thus, they can use their understanding of speeding cars, as represented by pictures, to understand force and acceleration, as represented by numerals and graphs.

Technological Perspective

Networks

During the next 10 years, pressure from four market forces will drive service providers to support broadband (10 Mb/s to 100 Mb/s) and wideband (greater than 100 Mb/s) demands for metropolitan-area networks (MANs) and wide-area networks (WANs):

- Increases in computing power.
- The public's growing appetite for media-rich information.
- Increases in workgroup computing (that is, groupware).
- Performance expectations based on the broadband and wideband capabilities of local-area networks (LANs).

Encircling the McAuliffe community of our scenario is a switched, high-bandwidth, wide-area network composed of fiberoptic cable and high-capacity video servers. The network is extended into homes, schools, automobiles, and offices by an amalgam of fiber, coaxial cables, wireless communication, and a few residual copper wires. Its capacity is increased by a variety of software and hardware compression and decompression utilities. The network is connected to networks around the world via satellite and microwave. Tapped into the network are a range of electronic devices that act and look sometimes like telephones, sometimes like televisions, and sometimes like computers, but they all communicate with each other. Sometimes they are combined into a single information-entertainment "teleputer." This network interconnects the various devices we have described and supports the connections between school, home, and work.

Personal Digital Assistant (PDA)

Learners and teachers will have small, wireless, very powerful information appliances at their disposal and within reach of their budgets in 10 years. Capitalizing on trends in miniaturization, manufacturers are packing more and more computer power into smaller and smaller cases. These developments herald a new class of computing device called a personal digital assistant (PDA). Prices of these devices are dropping rapidly, and, well before 2005, their price points will meet those currently offered by more specialized game platforms such as Nintendo. For example, most analysts anticipate that prices for Apple Computer's Newton PDA will fall to $200 or less by 1996.

Because they carry their PDAs everywhere, learners in our scenarios can work on their projects regardless of their location. In addition to approaching the task in a structured way, students work opportunistically, adding voice annotations, comments and ideas from friends and parents, and pointers to new information that arise during discussions. The major importance of these devices is that they bring computer processing and communications to situations anytime, anywhere. These capabilities will enrich many "informal" (outside the physical school building) learning situations, such as those that occur in the home.

Interactive Digital Video

Cable service providers are scrambling to provide interactive digital video services. As first steps, they are putting in place the infrastructure to provide video-on-demand and interactive home shopping as a replacement for conventional subscriber TV. They are examining both the impact and the requirements of such services in testbeds across the country (27). And, fueled by customer surveys that already underscore the attractiveness of these offerings, companies are building the video servers and set top boxes necessary to support these initiatives. One can already preview modest examples of these capabilities in hotels that offer guests the option to select and watch a movie at a time that matches their schedule or check out through the TV without going to the front desk. The advent of digital video-on-demand, coupled with the development of user-friendly agent technologies, will allow people to search video servers for specific kinds of information and make selections just as people today search and retrieve information from conventional databases.

In this scenario, both the replay of the race and the telecourse that Mr. Zamora is taking are available on large digital video servers. Carmela and her fellow students will also store their multimedia reports on these servers. These and other resources are available to members of the community as they are interested in using them.

Large, Color Display

It is likely that in the next 10 years flat-screen technology will improve sufficiently to accommodate modest display sizes in limited locations. The federal government has made a financial commitment to keep the United States competitive in this technological arena. For example, Xerox Corporation has recently received significant amounts of government funding to develop flat-panel technology for the U.S. military. We expect that in 10 years, following this developmental phase, the prices of large (4-ft x 3-ft) flat panel displays will reach price points equivalent to today's high-end consumer televisions ($2,000-$3,000).

In this scenario, the community has access to this still-expensive technology through the multimedia performance auditorium at the McAuliffe Learning Center. This display serves the important purpose of providing a common experience to a large group of people. The community members can participate in the achievements of their children and share in the satisfaction of their accomplishments.

IMPLICATIONS

Reiterating the point that began this paper, the vision that we present has significant implications for social change that go beyond the development of advanced technologies. Some of these implications we have embedded in our scenarios and their analysis. Others are more pervasive and represent the larger social context beyond school, home, and business connections and relationships. Making the vision that we present a reality will depend on changes in the way teachers teach and use technology, on the way education is supported and schools are held accountable, and on the universal availability of the services we describe.

Teachers and Teacher Training

Sheingold (34) concludes that the human side of technology introduction is a much bigger barrier than lack of technology per se. To fulfill our vision, teachers would need to learn not only to use the various technologies described in our scenarios, but also to design, structure, guide, and assess progress in learning centered around student projects.

This kind of teaching, which most teachers have rarely experienced in their own education, requires wide-ranging subject matter expertise, creativity, and intellectual confidence. Teachers need to help students design projects that will incorporate important content and be able to provide key ideas or strategies for helping students overcome impasses encountered in their work. Teachers need to be comfortable letting their students move into domains of knowledge where the teachers themselves lack expertise; teachers need to have the intellectual confidence to be willing to model their own reasoning process when they encounter phenomena they do not understand or questions they cannot answer. Teachers need to be creative in finding ways to embed measures of student understanding within group projects, no easy task when multiple groups are working concurrently and different students assume different roles within their groups. Teachers must be able to roam from group to group physically and electronically, providing stimulation and coaching without dominating the group process.

This new role for teachers is challenging and requires a very different kind of teacher education program, one in which prospective teachers are taught in the way we wish them to teach, and technology use is integrated into all preservice education classes rather than treated as the topic for a single, isolated class. Today's teachers need a great deal of professional support for learning to teach in new ways and to incorporate technology into these practices. They do not need the one- or two-hour workshop that is so prevalent today. They need regular blocks of time built into their work schedules in which they can plan project-based, technology-supported activities and assessment methods, as well as opportunities to observe classrooms where such work is going on. They need a chance to interact with a professional group of colleagues interested in the same kinds of instructional approaches and subject matter to get feedback on their new approaches, pointers to useful information, and encouragement for getting over the inevitable setbacks. Technology can help develop such groups through electronic networks and through "video clubs," in which teachers share and discuss videotaped excerpts from their classrooms. However, administrators and policy-makers need to provide the resources to support time for teachers to engage in these activities and develop expertise in their new roles.

If learning and teaching change in the ways we envision in these scenarios, the profession of teaching will change drastically. Teachers will assume a more executive role, setting goals and providing guidance, support, and evaluation, but letting the students carry out most of the learning activities. This new role entails curriculum development (as they work with students to design projects), team building, diagnosis of individual learning needs, assessment of individual student progress, and exploration of questions in a broader, unspecified range of content domains. Just as business professionals employ a variety of technology tools to increase their access to information and ability to make sense out of it, teachers will need a range of technology supports for designing learning materials, performing assessments, keeping track of curricular goals and achievements, and communicating with other teachers, information resources, students, and parents. No longer will teaching be the single profession in which practitioners cannot expect ready access to a telephone. Teachers will need to have technology tools available to them for their own as well as their students' use.

The teachers we describe, with well-developed skills as technology users and greater interaction with the worlds of research and commerce, are likely to find an increase in their status and in the number of nonteaching opportunities available to them. Side effects of this change in role could well include pressure to increase teacher salaries and a greater diversity among those who choose the profession.

Accountability and Public Support

From a public policy perspective, accountability concerns are a driving force in federal, state, and local education spending. Federal and state education agencies are offering local jurisdictions more flexibility in their education programs in exchange for accountability with respect to curriculum standards. Some might infer quite different visions of technology use from those described here, based on trends stressing curriculum standards and assessment of student performance relative to those standards. One could extrapolate from the national Goals 2000 legislation to the use of technology as the transmission mechanism for "approved" instructional content tied to curriculum standards and as a tool for collecting student assessments (for example, through computerized adaptive testing, which permits the coverage of more content with fewer test items per student). Many software publishers are looking forward to the development and voluntary adoption of national curriculum standards because they have the potential to create broader markets for instructional software tied to a single national curriculum, rather than the patchwork of state and local curricula that makes software design difficult and fragments the market.

We offer a very different vision of technology use, one in which the same kinds of technology tools used in work settings and homes are available to students and teachers, and are incorporated into challenging learning activities where students design projects around their own interests with guidance and support from their teachers and outside mentors. We have not ignored these policy concerns, however. We suggest that sophisticated software tools can be developed to support teachers in injecting important curriculum content into student projects and in keeping track of student achievement of instructional goals. This technological aid is quite feasible, provided that teachers have the training and time for its use.

What is perhaps less clear is public acceptance of this approach to learning and of a system of assessing students in the context of authentic group projects. As Cohen (8) points out, the majority of the public adheres to a very conventional model of education as knowledge transmission and assessment as performance on standardized multiple-choice tests. In many cases, departures from conventional content, teaching practices, or assessment are seen as attempts to avoid high standards. Parents want to know where their children stand in relation to other children and where the student body of their school stands in relation to those of other schools on traditional academic subject matter.

Our scenario for the future requires a real change in this perception. It will come about only if there is increased dialogue between educators and the community they serve, as well as strong evidence that project-based learning activities support the attainment of higher skill levels and that authentic assessments provide information that is at once educationally useful *and* predictive of how well students will perform future tasks of interest, whether college performance or ability to function effectively on the job. Given the difficulty of making widespread, fundamental changes in teaching practices, a strong body of research and evaluation evidence supporting these practices must be generated and disseminated to policymakers and the public if the kinds of practices we describe are to be commonplace in the year 2005.

Equity and Access

The biggest assumption in our scenarios is that students and their families will have near-universal access to high-end technologies. As technology connects learning environments and homes, it becomes increasingly important that differences in socioeconomic status not create an electronic form of school segregation between the technological haves and have-nots. Government and school programs and regulations will need to assure the accessibility and affordability of at least a minimum form of network service for all homes.

Although the growth in the number of computers and video-based technologies in schools has been exponential (2), the number of hours per week that individual students have access to technology is still very low in most schools. Moreover, those schools serving children from economically disadvantaged homes have less access to technology than do those serving more affluent communities (3) and, when they do have access to computers, are less likely to use them in ways other than drill-and-practice (12). In some states, school budgets are stretched so tightly that students must share basic texts; under such circumstances, teachers have a hard time building enthusiasm for learning to use new technologies.

There are positive signs, however, that the issue of equity is getting more attention. School financing mechanisms that leave areas with low property values with very limited per pupil educational funding are being challenged successfully in many states. At the same time, federal compensatory education programs are focusing more on schools serving the largest proportions of poor children. Federal guidelines are encouraging schoolwide programs and supporting the acquisition of technology and implementation of parent involvement programs as part of the effort to improve the educational prospects for children at risk of school failure.

Corporate support for education programs, particularly programs that incorporate technology, is at an all-time high and is likely to continue. The business community has become much more aware of its dependence on a well-educated workforce and of the changing cultural, gender, and ethnic composition of that workforce. Many corporations are making a particular effort to reach out to schools serving large numbers of children from less affluent homes, where computer technology is usually absent.

Current trends are not sufficient to reach our vision, however. Stronger efforts are needed on the part of federal, state, and district education agencies to make sure that schools serving larger concentrations of students from poor homes have not only equal access to equipment, but also equity in terms of the quality of technology-supported learning activities.

The concentration of government resources for technology in schools serving larger proportions of children from low-income homes will not bring real equal opportunity, of course, if the students do not have the same kinds of home resources used by other students and their caregivers. Our scenarios assume that a rich array of broadband services will be as commonplace and low in cost as television or the telephone. Without something approaching universal access and perhaps special rates for low-income households, we will not see the kind of across-the-board parental participation described here.

Another way to make technology accessible to parents is to make school equipment and services available during nonschool hours. Part of the scenario takes place in a technologically and socially rich community center located in the school. The coordination and co-location of community groups, social services, and educational programs can increase the impact of these services and increase their efficiency. Making these resources available to parents and students during nonschool hours can further increase impact and reinforce educational goals. As a place where parents and children come together to engage in learning activities, the learning environment can become the center for building communities of understanding.

CONCLUSION

The technological developments that we have discussed will be driven to a large extent by the business and consumer markets and funded by private capital. There is an important role, however, for government leadership, regulation, and support.

Central to our vision of communities of understanding, of course, is the community. Community leaders will play a pivotal role in making education the focus of community life and in nourishing the values that support education.

State and federal governments also can facilitate the development of communities of understanding in the policies and regulations that they make related to the emerging National Information Infrastructure (NII). Current models of the NII envision schools connected to each other and to libraries and museums. This level of interconnection is insufficient to realize our vision; schools must also be connected to homes and workplaces. As state and federal agencies review regulatory policies, they should require telephone companies and cable companies to provide phased-in universal service as they install advanced technologies, much as telephone companies are currently required to provide universal voice services. At the same time, policies should be structured so that service providers are responsive to community needs, much as current structures require cable companies to negotiate with local communities around the terms of their franchise. Policies and funding should encourage and support the experiments of local communities to interconnect schools, homes, and workplaces to support education.

In forming policies, it is vitally important that differences in socioeconomic status not result in an electronic form of segregation between the technological haves and have-nots. Policies will be needed to assure accessibility and affordability of at least a minimum form of network service for all homes, schools, and communities. Furthermore, it is important that this minimum service be interactive. An NII that allows some to both create and receive information while others are able only to receive it would institutionalize radical inequities and disenfranchise segments of society. Equity and access must be paramount considerations.

Finally, state and federal agencies dealing with education, labor, commerce, and science and technology should act in a coordinated fashion to encourage collaboration between the public and private sectors and to foster the development of tools, materials, services, and resources that support educational reform and make the NII pay off for students and schools.

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